402 Rec'd PCT/PTO 10 NOV 1999

METHOD AND APPARATUS FOR MONITORING HAEMODYNAMIC FUNCTION

BACKGROUND OF THE INVENTION

The present invention relates to a method and
apparatus for monitoring haemodynamic function in humans
and animals and, particularly, but not exclusively, to a
method and apparatus for monitoring haemodynamic function
in humans and animals during anaesthesia and surgery, and
its relationship to anaesthetic depth.

During anaesthesia and surgery on a human or animal
subject, the subjects haemodynamic respiratory,
neuromuscular and neurological functions are monitored as
indicators of the condition of the health of the subject
as anaesthesia and surgery progress. In general, as
anaesthetic (depth) increases, haemodynamic, respiratory
and neurological function are depressed or decrease (ie.
there is a dose-dependent relationship). During any
operation, it is important that adequate perfusion is
maintained (ie. oxygenated blood reaches all vital organs
including the brain, heart and kidneys). Tissue oxygen
delivery is dependent on the level of perfusion or blood
flow (cardiac output [CO]) and the amount of oxygen in the
arterial blood (Arterial Oxygen Content, CaO_2).

Haemodynamic function (causing blood flow to vital organs)
is therefore carefully monitored and any changes which
indicate that haemodynamic function may not be optimum
will alert the anaesthetist who may adjust the anaesthetic
dose to compensate ie., to vary the depth of anaesthesia
by adjusting anaesthetic depth.

Traditional monitoring of haemodynamic function in
anaesthetised patients undergoing surgery, in particular
humans, is based on cardiac auscultation, an ECG (electro
cardiogram) and blood pressure measurement. Cardiac
auscultation will detect the rate of heart beats. The ECG
directly monitors cardiac rhythm (electrical rhythm of the
heart) and indirectly monitors the pulse rate (assuming
the electrical rhythm causes an organised heart muscle
contraction). Blood pressure monitoring devices measure

blood pressure, usually measure pulse rate and the information obtained is used by clinicians/anaesthetists to indirectly make inference about (estimate) haemodynamic function, i.e., cardiac output (total blood flow) and

5 organ perfusion. The pulse rate, cardiac rhythm, blood pressure, and inference about haemodynamic functions provide the information necessary to give the anaesthetist an overall picture of haemodynamic function during anaesthesia and surgery.

10 This type of traditional monitoring of haemodynamic function, in particular the use of blood pressure monitors, is subject to a number of problems.

Indirect blood pressure monitors (systems using a pneumatic cuff and a method to detect the arterial pulse)

15 are inaccurate in small animals, horses and human infants and automated devices can be expensive. Direct blood pressure monitors (systems using a catheter placed in an artery, connected to a pressure measuring device) are accurate but invasive, complex and expensive.

20 Catheterisation of an artery is also NOT done without some risk of complication to the patient.

Further, the general perception in anaesthesia has been that good blood pressure equals good haemodynamic function. That is, if the blood pressure is good, it is

25 taken as an indication that there is adequate blood flow to ensure perfusion of all the vital organs. During anaesthesia and surgery good blood pressure together with good results for the other indicators (cardiac rhythm, pulse rate, etc) has generally been taken to mean that

30 everything is going well for the patient.

The majority of anaesthetic agents depress cardiac output in a dose dependent fashion. Generally, therefore, low blood pressure has been taken to indicate that anaesthetic dose should be lightened and high blood

35 pressure that anaesthetic dose should be increased (although the other indicators also have a bearing on anaesthetic dose and the anaesthetist will take all

indicators into account before deciding on the appropriate action).

The present applicants have realised that blood pressure is not in fact as good an estimator of cardiac
5   output or perfusion during anaesthesia and surgery as has traditionally been considered. Firstly, indirect measurement of blood pressure is inaccurate and secondly it is, in fact, frequently negatively related to total blood flow (cardiac output) and tissue oxygen delivery.
10   There is a recognised relationship between blood pressure, cardiac output and vascular resistance, as follows:

Cardiac Output = Blood Pressure (MAP-Right Atrial Press) ÷ Vascular Resistance.
15   One major problem with the usual assumption that blood pressure gives an indication of cardiac output is that none of the usual clinical measurements (auscultation, electrocardiogram, blood pressure) provide any information about vascular resistance.
20   During surgical procedures at usual anaesthetic levels, it is believed that the subjects body may still experience and respond to painful stimulation, although the subject is not consciously aware of the pain. The body, however, produces its standard sympathetic nervous
25   system response to the painful stimuli, including catecholamine release, resulting in vasoconstriction. The applicants believe that such responses lead to increases in blood pressure during surgery being accompanied by a decrease in cardiac output. This is exactly opposite to
30   the relationship between blood pressure and cardiac output which clinical anaesthetists have traditionally assumed. During painful surgery, therefore, rather than a direct positive relationship between blood pressure and blood flow there is believed to be a variable relationship which
35   may even be in a negative direction.

Given the above observation, and also the fact that non-invasive blood pressure monitors are inherently

inaccurate, it is clear that, in anaesthetised patients undergoing surgery, blood pressure cannot be relied on as an accurate estimator of haemodynamic function.
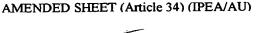
SUMMARY OF THE INVENTION → The present invention provides a method of monitoring
5   haemodynamic function in a human or animal subject, comprising monitoring changes in blood flow in a peripheral blood vessel or tissue bed, to provide an indication of changes in cardiac output.

The method preferably finds most application during
10   anaesthesia and surgery.

It is believed by the applicant that the monitoring of changes in peripheral blood flow will provide a more accurate indication of changes in cardiac output than that inferred from monitoring blood pressure. It is thought
15   that an increase in blood flow in a part of the body is more likely to indicate an increase in cardiac output, as compared to an increase in blood pressure, considering the limitations discussed above relating to using blood pressure as a cardiac output indicator during anaesthesia
20   in surgery.

In anaesthesia and surgery, it is all important that haemodynamic function be maintained such that sufficient oxygenated blood reaches the vital organs, e.g. brain, liver, etc. Good cardiac output is a good indicator of
25   whether there is sufficient blood flow to perfuse the vital organs, particularly during anaesthesia where patients usually breathe high inspired concentrations of oxygen.

Blood flow in an anaesthetised subject may be
30   monitored in a number of ways. Cardiac output can be monitored directly, using indicator dilution techniques such as by the insertion of a pulmonary artery, thermo-dilution, cardiac catheter, for example. This method is intermittent, invasive, requiring cardiac
35   catheterisation, which is not risk free and is not preferred, although insertion of such catheters provides an accurate measurement of total blood flow (cardiac

output). Indirect cardiac output or aortic blood flow measurement may also be made using 2 or 3-dimensional pulsed Doppler cardiac ultrasound, but with computer generated colour flow enhancement display this is very
5   expensive, not accurate, technically difficult and is very sensitive to probe position, movement of the subject or the measuring probe such as occurs during surgical manipulation.   In addition it requires a person to continuously hold the transducer on the body in a constant
10 position.
         There are a number of devices on the market which the applicant has found could be adapted for monitoring blood flow in blood vessels or tissue beds, non-invasively, relatively inexpensively and generally being relatively
15 non-movement sensitive. Such devices are particularly suitable for monitoring changes in blood flow in peripheral blood vessels, which the applicants believe will still provide a relatively good indication of changes in cardiac output. The method of the present invention is
20 preferably applied by continuously monitoring changes in blood flow, preferably in a peripheral blood vessel, to provide an indication of, changes in cardiac output. For practical clinical application, it is preferred to monitor blood flow in parts of the body where access is easier
25 and, in particular, blood flow in peripheral blood vessels. It may be difficult to measure the actual blood flow in a peripheral blood vessel as, unless an invasive technique is used, the diameter of the peripheral vessel(s) can only be estimated. Changes in blood flow in
30 peripheral vessel(s) can be monitored reliably, however. These changes can be used to estimate changes in cardiac output (total blood flow) we believe, quite reliably. Changes in blood flow in the peripheral vessel during anaesthesia and surgery can, therefore, be utilised by the
35 anaesthetist to adjust dose, eg. if blood flow in the peripheral vessel should fall, then the anaesthetist can imply corresponding falling cardiac output and can reduce

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anaesthetic dose to compensate (also taking into account
other monitored factors, as discussed above). Changes in
blood flow in the peripheral vessel, therefore, give a
relative indication of changes in total blood flow
5   (cardiac output).

Blood flow devices are known which detect blood flow
in peripheral blood vessels of subjects, by employing an
ultrasound sensor which uses the Doppler effect to detect
either red blood cell motion or blood vessel wall motion.
10   A signal is produced to simply indicate that motion is
occurring (ie. the signal is either on or off/present or
absent). An example of such a device is produced by Parks
Electronics of Aloha, Oregon, USA. Presently, such a
peripheral blood flow monitor is used together with a
15   occlusive cuff and aneroid manometer to indirectly measure
blood pressure. The occlusive cuff is tightened to the
point that the monitor registers that there is no blood
flow in a peripheral artery and the pressure is then read
from the manometer. This method only allows the operator
20   to obtain systolic arterial blood pressure. The Doppler
monitor is therefore only used in this application to
determine whether there is blood flow or whether there is
not any blood flow, ie. "on" or "off".

A more advanced continuous wave Doppler device can
25   print a pulsatile wave form based on the frequency and
volume of the reflected Doppler, and calculate the peak
and mean velocity of the blood flow. Such a device is
manufactured by Hiashi Denki Company Limited in Japan (the
ES-1000 SPM and ES-1000 SP).

30   As far as the applicants are aware, no such Doppler
monitor has been used for the purpose of monitoring
haemodynamic function during anaesthesia. Indeed, none of
the prior art devices are suitably adapted to be useful
for use in such an application.

35   The present applicants have utilised a Doppler
ultrasound device as a blood flow monitor, to provide a
signal whose characteristics preferably varies depending

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on the amount of blood flowing in a particular peripheral artery, in order to provide at least a relative indication of changes in total blood flow (cardiac output). This device is used in one preferred embodiment of the method

5   of the present invention.

Pulse oximeters measure the absorption of infra-red radiation by red blood cells in a peripheral vascular bed in order to determine the oxygen saturation of the blood. Since the amount of infra-red radiation absorption depends

10   on the amount of blood, such a device may be adapted, in accordance with an embodiment of the present invention, to provide an indication of relative changes in blood flow in the peripheral vascular bed. This measurement of changes in blood flow may be used as an indication of changes in

15   total blood flow.

In yet a further embodiment, a colour chart may be utilised to estimate changes in blood flow in a tissue bed that has a high density of superficial blood vessels by reference to the colour of the mucous membrane in that

20   tissue bed, eg. gums, tongue, lips, etc. Again, this provides a relative estimate of changes in total blood flow. Colour charts are designed by clinical observation of control subjects under various conditions and relating the observed colour to measurements of blood flow. In the

25   limit, a colour chart is not even necessary to carry out the method of the invention, mere practiced observation of an appropriate tissue bed by a skilled anaesthetist could be used to estimate changes in mucous membrane colour and therefore in blood flow in that area and therefore provide

30   a relative estimate of total blood flow.

The information obtained from monitoring blood flow will be used together with information from an electro cardiogram and measurement of blood pressure to provide a total picture of the haemodynamic condition of a subject

35   during anaesthesia and surgery. This will give sufficient information for the anaesthetist to properly evaluate the haemodynamic condition of the subject and vary anaesthetic

dose accordingly.

Preferably, where a blood flow monitor is used, the method of the present invention includes the further step of applying a regression analysis to the signal produced

5   by the blood flow monitor. Preferably, the regression analysis applied involves the steps of monitoring in an animal or human subject either cardiac output, tissue O_2 delivery (in a subject under anaesthesia breathing a high inspired amount of O_2, arterial oxygen content is

10 generally constant as changes in tissue oxygen delivery reflect changes in cardiac output) against the signal from the blood flow monitor. The data can be used to produce a plot which can be described by regression analysis. The regression equation can be used to calibrate the actual

15 output of the blood flow monitor to provide a more accurate relative indication of CO or tissue oxygen delivery.

Preferably, the method also includes the further step of making a further adjustment to the signal output by the

20 blood flow monitor by applying changes in heart rate as a co-variant factor. This has been found to further improve the estimate of CO of tissue oxygen delivery.

The present invention further provides a device for monitoring haemodyanmic function in a human or animal

25 subject, comprising a blood flow monitor arranged to monitor changes in blood flow in a peripheral vessel or tissue bed, to provide an indication of changes in cardiac output.

Changes in blood flow in a peripheral vessel can

30 preferably be used to provide an indication of changes in cardiac output. By "changes in blood flow" is meant changes of degree, not merely presence or absence of flow.

Preferred blood flow monitors are able to non-invasively monitor blood flow in peripheral blood vessels

35 and provide an output signal who's characteristics vary depending upon actual blood flow in the peripheral vessel(s) being monitored. As discussed above in relation

to the previous aspect of the present invention, changes
in blood flow in a peripheral vessel provides a relative
indication of changes in total blood flow (cardiac
output). Preferably, the device comprises a display or
indication means, and means for receiving the signal from
the blood flow monitor and processing it to drive a
display or other indication means to provide an indication
of blood flow, preferably changes in blood flow, which can
be monitored by the clinician, such as an anaesthetist.

In a preferred embodiment, the device may be
pre-calibrated for a particular subject by, firstly,
taking the strength of the blood flow signal from the
blood flow monitor when the patient is at rest prior to
induction of anaesthesia and surgery and, then using an
occlusive cuff to shut off blood flow to the peripheral
vessel, obtaining a zero signal. The display on the
device can then preferably be set between the upper rest
resting blood flow rate and the zero blood flow rate. The
device preferably includes an alarm warning indication
means to provide an indication of an alarm situation, if
the blood flow in the peripheral vessel drops below a
certain pre-determined amount.

The device is preferably adapted to give an output
which is particularly designed to be useful for an
anaesthetist monitoring a subject under surgery. The
display preferably provides indications of changes in
blood flow in the patient and, preferably, an alarm is
provided to sound or provide an indication of an alarm
condition when a blood flow change occurs which indicates
that a person is either anaesthetised too deeply or not
deeply enough. The display may be graded with markings
indicating the changes in blood flow in relation to
anaesthetic conditions, i.e., too much anaesthetic, too
little anaesthetic, etc.

The device is also preferably arranged to apply an
adjustment factor to the blood flow monitor signal, the
adjustment factor being based on a regression analysis of

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actual subjects. The device is also preferably arranged
to provide a further adjustment to the signal by taking a
co-variant as an input to adjust the signal, and,
preferably, the co-variant is heart rate. The adjustment
5   preferably results in an improved output signal.

The blood flow signal may be derived from a pulse
oximeter, Doppler monitor, as discussed above.

In an alternative embodiment, the blood flow monitor
may comprise a colour chart including coloured patches to
10   be compared with an area of the body of the subject, eg.
the lips or tongue. The colour chart would be
pre-determined for an "average" subject of the particular
animal type (or human being) to give an indication of
blood flow depending upon the colour of the body part at
15   the time.

A blood flow monitor and method in accordance with
the present invention may have applications other than
during anaesthesia. For example, a device which is
arranged to monitor changes in blood flow in peripheral
20   vessels or peripheral tissue beds may have application in
cardiac stress testing, and other applications.

BRIEF DESCRIPTION OF THE DRAWINGS

Features and advantages of the present invention will
become apparent from the following description of
embodiments thereof, by way of example only, with
25   reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram of a device in
accordance with one embodiment of the present invention;

Figure 2 is a schematic perspective view of a
external appearance of a device in accordance with the
30   embodiment of figure 1;

Figure 3 is a view of an example operating display of
the device of figure 1, for a human subject during
anaesthesia in surgery;

Figures 4 through 7 show various displays of the
35   programming (set up) and alarm setting functions,
displayed as for animal operation;

Figure 8 is a view of a "colour chart" in accordance

with an embodiment of the present invention; and

Figure 9 is an example plot of cardiac output or tissue O_2 delivery against "perfusion index" to demonstrate how regression analysis is to be applied to
5   the output signal of a blood flow monitor in accordance with an embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A device in accordance with an embodiment of the present invention, for use with a method in accordance with the present invention, is illustrated in figures 1
10   through 7. The device can be used as discussed in the preamble, to monitor changes in blood flow in a peripheral blood vessel of a human or animal subject during anaesthesia and surgery. This gives an indication of relative changes in total blood flow (cardiac output) as
15   one of the indicators for enabling the anaesthetist to monitor the subjects haemodynamic condition and suitably adjust anaesthetic dose. Monitoring peripheral blood flow to provide an indication of changes in cardiac output, as opposed to using blood pressure, runs contrary to
20   anaesthesia practice over the past one hundred years where blood pressure is used in surgery to indicate changes in haemodynamic function or cardiac output. As discussed above, the present applicants believe that, because of responses to painful stimuli during surgery, blood
25   pressure is neither a reliable or positive indicator of changes in cardiac output. They believe that either monitoring of total blood flow or, as in the preferred embodiment of the invention, monitoring of changes in blood flow in a peripheral artery during anaesthesia in
30   surgery, will provide a much better positive indication of relative changes in total cardiac output.

The method of monitoring haemodynamic function during anaesthesia and surgery in accordance with the preferred embodiment of the present invention, also preferably
35   includes the steps of monitoring blood pressure, using standard equipment, monitoring ECG, using standard equipment and monitoring respiration using an airway

thermistor. The heart rate may be monitored using the ECG
device. The pulse rate may be monitored using the device
in accordance with the present invention, being determined
from the peripheral blood flow. These parameters,
5 together with blood flow, provide the total "picture"
required by the anaesthetist to enable monitoring and
adjustment of anaesthetic dose to ensure the haemodynamic
health of the subject.

      Figure 1 is a functional block diagram showing
10 components of an ultrasound based device for monitoring
blood flow, in accordance with an embodiment of the
present invention. The device, generally indicated by
reference numeral 1, comprises a Doppler transducer 2 for
monitoring blood flow in a peripheral blood vessel of a
15 human or animal subject. In operation, the transducer
will be affixed to the appropriate body part of the
subject eg. placed distally on the wrist or ankle of a
human being, or where an animal is the subject, on the
tail. Note that as an alternative to a Doppler transducer
20 2, a pulse oximeter adapted to monitor blood flow could be
used as the blood flow detector (transducer). In fact,
any device which is capable of detecting blood flow, in
the preferred embodiment in a peripheral vessel, could be
used.

25   Note that a further alternative, in accordance with
an alternative embodiment of the present invention, is to
use a device such as a pulse oximeter in addition to using
the Doppler transducer 2 to monitor the changes in blood
flow. The pulse oximeter is, in accordance with this
30 embodiment, adapted to monitor blood volume in a
peripheral tissue bed (rather than oxygen saturation which
is usually constant during anaesthesia where patients
inspire high concentrations of oxygen) and this may be
used to improve the estimate of changes in blood flow or
35 to enable estimation of changes in vascular resistance.
In this alternative embodiment, the device of figure 1
would also include a sensor and a pulse oximeter device

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providing an input about changes in tissue blood volume to
the micro computer 4 for processing together with the
perfusion input from the Doppler device. The following
description, however, relates to an embodiment which
5   employs a Doppler monitor only.

In this embodiment, a continuous wave Doppler
driver/receiver 3 is connected to the Doppler transducer
for transmitting and receiving ultrasound signals
therefrom. A microcomputer and interface 4 is arranged to
10   process the signal from the receiver 3, and drive the LCD
display 6 to produce an output indicative of changes in
cardiac output (substantially equivalent to tissue oxygen
delivery under high inspired concentrations of O_2). It
also controls and/or responds to the other peripherals, as
15   follows:

a serial interface 5 to an external printer;

a liquid crystal visual display 6;

a membrane keypad 7;

a control panel 8;

20   a loud speaker 9; and

a thermistor controller 10 for controlling a airway
thermistor (not shown).

Power is provided from the mains via a power supply
regulator 11, which is also provided with a back-up
25   rechargeable battery 12, in case of failure of the mains.

In operation, the microcomputer controller 4 operates
to process the signal from the Doppler transducer 2 to
determine changes in the blood flow rate in the peripheral
vessel and to control the liquid crystal display 6 to
30   provide an indication, preferably graphical indication, of
the instantaneous relative cardiac output at any time
during anaesthesia and surgery. It is preferred to give
an output of _relative_ cardiac output, rather than
attempting to produce an output indicative of actual
35   cardiac output. Attempting to obtain a measurement giving
actual cardiac output is very difficult because a) vessel
diameter is required or b) it assumes that changes in

blood flow or vessel diameter in one vessel similarly
reflect changes in the whole animal. Monitoring changes
in blood flow to provide an output relative to a
reference, such as the signal output by the blood flow
5   monitor when the patient is at rest prior to anaesthesia
and surgery, is much more convenient, and provides
sufficient indication to the anaesthetist to guide him to
control anaesthetic depth. The loudspeaker 9 is
controlled by the controller 4 to provide an audible pulse
10 signal and alarms should the blood flow fall below or rise
above pre-set levels. Preferably, the display 6 also
provides a visual alarm indication. The control panel 8
can be used to pre-set the blood flow display and alarm
limits, depending upon, for example, the size of the
15 subject and the species of the subject. It is envisaged
that a device would be provided suitable for operation on
a human subject and a separate device suitable for
operation on animal subjects, the animal subject device
preferably being adapted for use with a number of animal
20 species, control limits being pre-set for species and
animal size by the control panel 8. The microcomputer and
interface 4 is arranged to process the Doppler signal
output to give an indication of blood flow changes based
on the strength of the signal.
25   Figure 2 shows the external appearance of an example
device 1. Equivalent items to figure 1 are given the same
reference numerals. The entire device 1 is housed within
a robust housing 13. Brackets 14 are provided to hold a
reference manual giving operating instructions on the
30 device 1. The device is mounted on rubber feet 15 and has
a carrying handle 16. A plug 17 is provided for
connection to a mains power supply.
         In operation, before a subject is anaesthetised, the
Doppler transducer (sensor) 2 is positioned on the skin
35 surface, overlying a peripheral artery such as located in
the human forearm at the level of the wrist (radial or
ulna artery), on the plantar surface of the foot of a dog

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or cat (pedal artery) or on the ventral surface of the
tail (coccygeal artery). The device is attached to the
subject at rest while conscious and a flow rate
determined. The control pad 8 is then used to set a "base
5   line flow" rate and a base bar (reference number 20,
figure 3) will appear on the operating display. The base
bar will be used as a reference by the anaesthetist as the
"normal" flow rate of the conscious resting subject (ie.
prior to induction of anaesthesia). As an alternative,
10   the device may also be arranged to store a series of
"standard" base bars, being default settings for a
particular animal species/size of animal. This would be
necessary for animals which may not tolerate attachment of
the transducer while conscious. For a human subject,
15   however, it is preferable to pre-set the levels and the
display by monitoring of the individual subject.

Figure 3 shows an example operating display for a
human subject during anaesthesia and surgery. The left
hand side of the display, indicated by reference numeral
20   21, is taken up by a bar graph which graphically
continuously indicates peripheral blood flow rate based on
the signal obtained from the peripheral vessel, processed
by the controller 4 to provide the display. The base bar
20 is permanently in place on the graphical display and is
25   pre-set by monitoring the flow rate of the conscious
subject at rest, prior to the induction of anaesthesia.
All flow rates and flow alarms are determined relative to
this base bar 20. A high limit bar 22 and low limit bar
23 are also displayed. These can either be pre-set by the
30   anaesthetist or pre-stored in memory to automatically be
displayed depending upon the set base bar level and other
subject factors, eg. weight, age, etc. For example,
appropriate limits could be determined by clinical trials
and then stored in the memory of the device.
35   A moving flow marker 24 is also displayed. This
shows the actual real-time flow rate (relative to the base
bar). It is this marker 24 that the anaesthetist will

watch carefully to obtain an indication of changes in haemodynamic function. Preferably, the flow marker is arranged to flash. Should the rate fall to the lower limit bar 23 or rise to the high limit bar 22 an audible
5   alarm will sound and the numeric flow display 26 will flash. The anaesthetists attention will thus be drawn to the alarming level of perfusion or blood flow and appropriate action can be taken (eg. altering anaesthetic dose, administration of IV fluid, inotropic drugs etc.).
10   Note that it is unlikely during appropriate levels of anaesthesia during surgery in normal, healthy patients that blood flow will ever rise much above the base bar. This is because standard anaesthetics tend to depress (rather than stimulate) cardiac output in a dose dependent
15   fashion. Such a monitoring device can also be used for monitoring haemodynamic function during critical care such as post cardiac surgery. On this point, a novel device such as this is likely to provide precise clinical data on the effect of anaesthetics and surgical manipulation on
20   peripheral blood flow in humans and animals. However, there are applications of this device, such as cardiac stress testing (treadmill testing) of conscious humans or race horses, where blood flow could increase above the base line measurement.
25   Referring again to figure 3, the controller 4 also determines the pulse rate of the subject from the Doppler flow signal. This is displayed in the top right hand portion 25 of the display 6. The anaesthetist can also therefore view pulse rate, at a glance. The bottom right
30   hand corner of the display 26 displays the actual (instantaneous) peripheral blood flow rate in alphanumeric.
        Should the probe signal change caused by transducer or skin movement relative to the artery or loss of
35   acoustic coupling or otherwise malfunction, a "probe error" display will flash 27.
        Switching the device on and taking no further action

defaults the screen to the monitoring display (figure 2).
All input and control of the device is set by rotating
knob 80 (figure 2) to select function or value and
pressing enter to accept function or value.

5   Upper and lower limit thresholds may also be set for
pulse rate, such that if the thresholds are reached
audible alarms/visual alarms are provided. A breath to
breath audible output and a numeric display of respiratory
rate, may also be provided if an airway thermistor is
10   employed.

Figures 4 through 7 show examples of screen displays
which may appear during initial set up of the apparatus
prior to operation on a human or animal subject. The
example screens are based on the device as designed for
15   animal use. This is generally the same as what would
appear in the device as designed for human subjects,
except that it is envisaged that there would be no screen
for default species settings (figure 5) although default
settings based on body size could be introduced.
20   Alternatively, all the settings for the alarm function
could be entered manually (figure 4). After selecting
either the default settings (figure 5) or entering the
alarm settings manually (figure 4), the device will then
display the result and settings as selected (figure 6)
25   before reverting to the "running" display associated with
the continuous monitoring function (a running display is
shown in figure 3 for a human being, but a similar display
would be shown for animal).

The boxed items of display (figure 4) ("Run", "Pause"
30   etc) are what can be selected by turning the knob 80. A
selected function displays as inverse display (ie. white
letters on black background). Depressing the knob will
then cause the numerical value to increase in magnitude to
a maximum number. Subsequently turning the knob by 10°
35   will move the selection to the next boxed item in a left
to right, top to bottom flow with wrap-around at bottom.
Turning the knob counter clockwise will reverse the

selection highlighting.

Figure 4 shows a typical data entry display for manual entry of the alarm settings, which enables entry of pulse rate high/low limits and flow rate high/low limits
5   ie. minimum, base and maximum levels for each item. These values can be set manually based on the preference/clinical experience of the anaesthetist. Alternatively, selection of alarm limits may be based on default settings as shown for animals.

10   Figure 5 shows a display for default settings which can be selected, which will be based on clinical trials for the particular species/weight of animal (Note that manually five entered default settings may be stored by the user in memory.) Figure 6 illustrates the screen with
15   the default settings which were either entered manually (figure 4) or selected (figure 5). Devices may obviously be designed with different default settings for different species and animal sizes, depending upon application.

Figure 6 is a diagram of the entered/selected alarm
20   setting display, also showing the rest of the control panel from figure 2, incorporating screen selection knob 80, mode button 31, enter button 32 and on/off switch 33.

For this example (10-20kg dog) using figure 6 "enter" can be pressed while the selection knob is set on "Animal
25   Class" to display the Animal Class display from figure 5. A 10-20kg dog will be class "3", the knob is turned 10° clockwise to highlight the numerical animal class function number 3 which results in the various high/low default limits shown in figure 6. Enter button is then pressed
30   which now selects the default settings (for class number 3) and changes the display screen to figure 6. Turning the knob 5° will increment by one value resulting in the display value being 1. Thus turning the knob to approximately 55° clockwise will set the value to 11 (a
35   15kg dog). The knob can be rotated counter-clockwise to decrement the values. Again the "enter" button is pressed which records and accepts the value. At this point all

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the values on the Data Enter display will change to the
default values for a 15kg dog. The highlighted box will
move to the RUN box assuming the "enter" button will be
pressed to accept all the default values and change the
5   display to Figure 7 - If a Run Display of particular value
is to be changed, eg. warning tone to OFF, the knob is
turned either clockwise or counter-clockwise to the
desired box. Pressing enter will toggle the value (to
on/off etc) and move the selection to next value (left to
10   right, top to bottom). When all values on the Data Enter
display are set and RUN is entered, the display changes to
the RUN display.

In the PAUSE mode (Figure 7), the display will be
inverse. All Data Enter values will be displayed on the
15   RUN display format.

The Doppler sensor is secured with the animal
sedated.

RUN is selected by turning the knob counter-clockwise
approximately 10° and "enter" button pressed. The monitor
20   will now start to function, updating the display
approximately every 15 seconds, showing heart rate, flow,
and moving the flow marker above or below the base value.
At any time during operation the knob can be turned to
highlight any value on the run display.
25   During the procedure, the base value may need to be
adjusted. Such as with re-positioning the patient for
surgery. Turn the knob to highlight the base value eg 2.0
Figure 3, press enter, turn the knob (clockwise or
counter-clockwise) to display the desired base flow, then
30   press enter. The monitor will accept the new base flow
number and readjust the High/Low limit bars.

With regard to the embodiments discussed above, the
output signal from the Doppler transducer is a signal the
amplitude and/or frequency of which varies depending upon
35   the rate of blood flow in the peripheral vessel being
monitored. As discussed above, the signal can therefore
be processed by the micro computer 4 to control a display

- 20 -

to give an output indicative of changes in total blood
flow as the changes in blood flow in the peripheral vessel
correlate with changes in total cardiac output (CO). In a
clinical situation, such as during anaesthesia in surgery,
5   the accuracy of this correlation is important, i.e., it is
important that the displayed changes correlate well with
the actual changes in cardiac output or tissue oxygen
delivery. If the display gives an inaccurate reading,
particularly in the critical range (i.e., in the region of
10   the alarm levels) then information given to the
anaesthetist can be misleading and ultimately lead to a
dangerous situation.

     The present applicants have found that the accuracy
of the correlation between the changes in the output
15   signal from the Doppler transducer and changes in cardiac
output can be much improved by further processing of the
signal to adjust the signal by a factor which is based on
regression analysis of actual experimental subjects. They
have also found that the correlation can be even further
20   improved by adjusting the processed signal by employing a
co-variant factor, in the preferred embodiment being heart
rate. Adjustment of the signal using these factors
preferably leads to a more accurate output and the
microprocessor is preferably arranged to process the
25   signal from the Doppler transducer by including
adjustments based on these factors.

     Figure 9 is a schematic plot of "Perfusion Index" in
relation to cardiac output (CO) or tissue oxygen delivery,
for a notional experimental subject, to illustrate how
30   regression analysis may be applied in accordance with this
embodiment of the invention. Perfusion Index is a term
the applicants have chosen to represent the processed
output of the Doppler device (or where another device is
being used to monitor blood flow, the output from that
35   device). The processed signal from the Doppler device,
which is a voltage output proportional to doppler
frequency change, whether it be amplitude or frequency,

provides an output known as the Perfusion Index. Ideally, this output will be directly proportional to cardiac output or tissue oxygen delivery (curve A of figure 9). During anaesthesia, high inspired amounts of oxygen are

5 applied so that the arterial oxygen content is relatively constant. Changes in cardiac output can be taken to be substantially the same as changes in tissue oxygen delivery, therefore, in these circumstances.

The ideal, unfortunately, is not the case. From

10 experiments with subjects, however, it is possible to plot Perfusion Index against CO or tissue oxygen delivery, by monitoring cardiac output with another device arranged to directly monitor cardiac output, and by applying a device such as a Doppler monitor to monitor "Perfusion Index", on

15 an experimental subject, to give a realistic plot, plot A in figure 9. The equation for the curve is:

$$y = ax + b$$

where y is in this case cardiac output or tissue oxygen delivery, x is Perfusion Index, a is the slope and b is

20 the intercept (see figure 9).

By adjusting the output of the Doppler device by modifying it by a factor corresponding to a and b, i.e., modifying it by using a regression analysis employing a experimental subject, a more accurate correlation of

25 Perfusion Index (i.e., the new adjusted Perfusion Index) with cardiac output or tissue oxygen delivery can be obtained. In the preferred embodiment, therefore, the micro computer 4 is arranged to modify the output of the Doppler receiver 3 by a factor relating to the regression

30 analysis. This has been found to provide a much improved output, i.e., a more accurate indication of the cardiac output.

In application, therefore, regression analysis is carried out by a monitoring perfusion index against

35 cardiac output or tissue oxygen delivery for a plurality of subjects. The results of the regression analysis are then used to calculate a weighting factor to be applied to

the output from the Doppler monitor, by the device in accordance with the embodiment of the present invention, in order to adjust that output to create a more accurate output indicative of cardiac output or tissue oxygen

5   delivery. In the example given in figure 9, a and b are calculated and y with the new adjusted output, is produced in accordance with the formula y = ax + b.

Note that tissue oxygen delivery = tissue blood flow (cardiac output) x arterial oxygen content.

10   A further improvement to the correlation of Perfusion Index to cardiac output can be made by further modifying the output signal from the Doppler transducer by making an adjustment for a co-variate factor.

Cardiac output = heart rate x stroke volume.

15   Cardiac output also = mean arterial pressure/vascular resistance.

There are therefore a number of variants which influence cardiac output and which may also determine the accuracy of an output signal from the Doppler monitor.

20   The applicants have found that, in patients anaesthetised for surgery, including a co-variate factor based on heart rate also results in an increase in the accuracy of the final output of the device. A co-variate factor relating to mean arterial pressure does not improve the output and

25   in fact degrades it.

Preferably, therefore, in accordance with the preferred embodiment of the invention, the output of the Doppler monitor is also adjusted by applying a co-variate factor, based on the heart rate of the patient. Again, a

30   number of experimental subjects are monitored to see what variation of the output of the Doppler monitor (perfusion index) occurs with pulse rate. A weighting factor is then applied to the output from the signal in accordance with detected heart rate for a patient, to further improve the

35   response of the device.

A further modification which may be made to the device is to process the output to provide an indication

of the "trend" of the output and also provide a display of
the trend. All measurements are stored periodically, for
example every one to five seconds, and a display which
gives the direction that the output is taking, i.e.,

5   either up or down, is provided for the anaesthetist. This
"trend" display can be useful in anaesthesia, and will
generally provide more direction to an anaesthetist as far
as anaesthetic dose required is concerned, than a straight
forward "number" display not indicating any trend.

10   As discussed above, the preferred Doppler device to
be used with the present invention is a continuous wave
Doppler. These are preferably cheap, easy to build and
portable. In operation, the ultra sound beam is
transmitted from one crystal and the reflected wave

15   received by another. The change in frequency of the
reflected signal is in part due to the velocity of the red
blood cell flow. The change in the amplitude of the
signal depends on the vessel, distance and tissue density
differences.

20   Vessel wall motion alters the high amplitude, of the
signals which influences the shape of the amplitude/time
spectrum of the reflected wave. This problem can be
minimised by using Doppler crystals with higher sound
frequencies (8 to 10 MHz). In addition use of front end

25   clutter filters designed to optimise the illumination of
reflected sound from skin, subcutaneous tissue and fat can
be employed, and this is preferred. Since the amplitude
and time lay of the reflected noise depends on the depth
and size of the blood vessel being analysed, the filters

30   are preferably specific for either body size (e.g., adult
human, child or neonate) or species (e.g., cat, dog,
horse). A toggle switch preferably enables the operator
to select the desired clutter filter (not shown in the
figures).

35   The change in time difference between the reflected
signal from the proximal and distal wall of the blood
vessel can be analysed and will indicate changes in blood

vessel diameter. An estimate of blood vessel diameter combined with the estimate of velocity of blood flow, can be used to give index of blood flow, which can be modified in accordance with the factors discussed above to give the

5   desired output (perfused index) which accurately correlates with Cardiac Output. As discussed in the preamble of the specification, other devices which are capable of monitoring blood flow could be used instead of continuous wave Dopplers.

10   As discussed above, a pulse oximeter may also be used to provide a monitoring device in accordance with the present invention.

        Pulse oximeters are currently designed to measure the transmission of red and infra-red light from haemoglobin

15   of the arterial blood and estimate the arterial oxygen saturation. However, changes in the reflective wavelength of the light from the tissue bed depend on:

        A.   Changes in the oxy-haemoglobin level.

        B.   Changes in the total mass of tissue including

20   red blood cells.

        Once a pulse oximeter is functioning on a patient, it assumes that the background tissue and blood "mass" is constant (fixed), it focuses on the pulsatile part of perfusions or blood flow wave form and therefore assumes

25   that changes in the wavelength of the light are due to changes in oxygenation.

        Typically during anaesthesia, patients breath high inspired concentrations of oxygen. Therefore, changes in light absorption are far more commonly due to changes in

30   the mass of red blood cells (i.e., the assumed to be constant light absorption) than to changes in arterial oxygenation.

        To modify a pulse oximeter, we need to work form the principle that using two light wavelengths (one in the

35   visible red spectrum and one in the infra-red spectrum): at the isobestic wavelength, the absorbing power of oxyhaemoglobin in the reduced haemoglobin is the same.

Therefore total absorbency depends only on the sum of the two and not the state of oxygenation. Therefore the total absorbency depends only on the total amount of blood present. As tissue blood flow increases or decreases, the

5 total absorbency at the isobestic point will change and this can be used to give a measure of the relative change in blood (mass) flow in the tissue bed. Such a device can therefore be used to monitor changes in blood flow in peripheral tissue beds.

10 Electromagnetic flow meters have been designed to be surgically implanted around large blood vessels such as the aorta and renal artery. It is possible that such a device may be adapted to be placed around a peripheral tissue bed, such as a finger or tail, to provide an

15 indication of relative changes in blood flow. This may not be accurate, however.

There is no reason that an electromagnetic flow meter could not be used in the present invention, by implantation of a cuff type flow meter around a blood

20 vessel. This is, however an invasive technique, and although it falls within the scope of the present invention it is not preferred.

Other available devices which could be adapted in accordance with the present invention are non-invasive

25 optical flow meters. These devices measure the absorption characteristics of light scattered by blood flowing through tissues such as skin surface, detecting this reflected light, analysing the frequency of the wave forms to obtain the mean peak light frequencies in estimating

30 blood flow. Problems with this approach are that the device only measures very superficial (i.e., skin surface) blood flow, which during anaesthesia is altered by vaso constriction such as caused by changes in body temperature. The device is also subject to movement

35 artefacts/vibrations such as caused by patient positioning, movement by surgical manipulations, restorations, vibrations from re-circulating water beds,

etc. It is therefore difficult to get a continuous measure from a wave (pre-anaesthesia) through to anaesthesia when positioned for surgery.

Further, the signal requires considerable damping to get a stable measurement, which sacrifices the accuracy of the "real time" measurement. It also relies on estimating the Doppler signal change in the scattered light to obtain the peak frequency and fails to measure perfusion of deeper tissues. Nevertheless, although not preferred, it is quite possible that such a device could be used in the present invention.

The above description is of a relatively sophisticated device which can be used with the method in accordance with the present invention. As discussed in the preamble, a primitive device, in the form of a "colour chart" can also be used. Colours indicating various flow rates would be established by clinical trials for various species in order to produce the colour chart. An anaesthetist will then have reference to the colour chart and compare with the colour of the part of the body concerned such as the oral mucosa, in order to monitor flow rate in the subject. An example colour chart is schematically illustrated in figure 8.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.